Shell Exploration & Production

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Subject: Model Result Comparison OOC Model Version 2.5 and Version 3.0

The purpose of this memo is to provide additional information about the dispersion modeling used to support Shell's proposal to construct a mudline cellar using a remotely operated vehicle (ROV). Shell's proposal was submitted to USEPA Region 10 with supporting dispersion modeling using OOC Model Version 3.0. The USEPA then used OOC Model Version 2.5 to verify Shell results, and some differences were noted. Additionally, Shell has used OOC Model Version 3.0 to support the 2015 drilling season NOI submittals. To help understand the differences in the model versions, Shell has performed the following:

- Summarized below how the model functions and what factors influence the results.
- Conducted further model runs using both versions of the model using input files provided by the USEPA.

Model Function

Numerical estimation methods have long been used to approximate the solution to ordinary and partial differential equations. High-speed computing allows for the solving of these mathematical equations in ways that were impossible before. Numerical modeling is useful in evaluating the behavior of discharges because sets of nonlinear differential equations have been developed to simulate the dispersion of constituents in the water column and along the seafloor. Using numerical estimation methods to approximate solutions to these equations has allowed scientists and engineers to develop a better intuition about nonlinear dynamical systems such as the dispersion of drill cuttings and muds discharges at an offshore drilling location. Smith et al. (2004) describes how field data on drilling mud and produced water dispersion in the Gulf of Mexico were used to verify the Offshore Operators Committee (OOC) Mud and Produced Water Discharge Model (the "OOC Model"). The ability of the OOC Model to predict the plume characteristics observed in numerous laboratory tests of plume behavior, covering a wide range of discharge conditions, has also been examined (Nedwed et al. 2004).

For a given set of input parameters, the OOC Model solves a unique set of non-linear partial differential equations simply by relying on two points separated by a finite difference. If the distance (in time or space) is too large for the simulation, then the error terms begin to add up and strongly influence the final outcome of the modeling runs. Partial differential equations, by their very nature, incorporate both time ***t*** and space **x** as independent variables; therefore, the selection of the model time step and cell size is critical. Numerical solutions to differential equations become more accurate as the step functions (either time or space) becomes smaller approaching the theoretical limit of zero. Therefore, for the OOC Model, smaller cell size (either time or space) produce more accurate results to the differential equation solutions. In terms of accuracy of the output parameters, maximum deposit thickness will decrease exponentially as cell size is increased (more accuracy) and the area affected by deposit thickness 1 cm or larger will increase linearly as cell size is increased (less accuracy). This behavior is inherent to the underlying equations and numerical methods used in modeling and not an artifact of the model version.

The difference in model results between Shell and the USEPA is primarily due to the use of different model time-step and cell size and not because of the different versions of the OOC Model. Shell's modeling used a 20 m cell size and a 900-second model time-step. The USEPA modeling used a cell size 20 m (in order to span a model domain of approximately 5 km with the 150 cells available in Version 2.5 of the OOC Model) and large time steps between 7,200 and 14,400 seconds. In addition, due to fundamental limitations of the now 15-year old program, a user of OCC Model version 2.5 can only execute a 7-day duration using these larger model time-steps.

Model Comparisons

Shell conducted a series of modeling exercises in order to reproduce USEPA validation results and to investigate the difference in the output for several parameters using OOC Model version 2.5 and OOC Model version 3.0. The inputs were derived from two data files provided by USEPA titled: Case-2.inp, and Case-1.inp. The model run results are shown in Table 1 and the model report is provided in Attachment 1. Results obtained from USEPA (USEPA V2.5) were compared to results obtained by Shell using different versions of the model (Shell V2.5, Shell V3.0)

When running OOC Model version 2.5, with identical input parameters, as shown in Table 1, both Shell and USEPA outputs, are as expected, identical, or virtually identical, for the parameters maximum loading, maximum thickness, total suspended solids (TSS), and area of deposition with thickness greater than 10 cm and 1 cm. This is the case for both the mean current and the maximum current case. When OCC model version 2.5 and OCC model version 3.0 are compared, for the mean current case the results are very comparable for all parameters. For the maximum current case, Model version 2.5 predicts by a factor of 1.5 to 50 lower values for maximum loading, maximum thickness, TSS, and area of deposition greater than 10 cm compared to Model version 3.0. Only the area of deposition greater than 1 cm is higher (by roughly of factor of two) compared to Model version 2.5.

Table 1: Comparison of OOC model Version 2.5 and 3.0 outputs using similar input parameters

	Mean Current Case				Max Current Case		
Parameter	**Shell V2.5**	**USEPA V2.5**	**Shell V3.0**		**Shell V2.5**	**USEPA V2.5**	**Shell V3.0**
Max Loading (kg/m2)	2362	2362	3198		298	298	1490
Max Thickness (cm)	89.1	89	120.7		11.3	11	56.2
TSS (mg/L at 100 meters)	536.2	536.2	530.9		4.1	4.1	200
Area (ha greater than 10 cm Thickness)	0.62	0.6	0.67		0.54	0.52	0.826
Area (ha greater than 1 cm Thickness)	4.53	4.4	4.59		6.75	6.96	3.437

When running OOC Model version 2.5, with identical input parameters, as shown in Table 1, both Shell and USEPA outputs, are as expected, identical, or virtually identical, for the parameters maximum loading, maximum thickness, total suspended solids (TSS), and area of deposition with thickness greater than 10 cm and 1 cm. This is the case for both the mean current and the maximum current case. When OCC model version 2.5 and OCC model version 3.0 are compared, for the mean current case the results are very comparable for all parameters. For the maximum current case, Model version 2.5 predicts by a factor of 1.5 to 50 lower values for maximum loading, maximum thickness, TSS, and area of deposition greater than 10 cm compared to Model version 3.0. Only the area of deposition greater than 1 cm is higher (by roughly of factor of two) compared to Model version 2.5.

Based on these findings and the underlying numerical estimation techniques utilized in the model, Shell believes that Model Version 3.0 is a better (and more conservative) predictor of dispersion characteristics for discharges of drilling muds and cuttings in the Chukchi Sea. Shell will continue to work with the Offshore Operators Committee (OOC) to assist in making an executable version of OCC Model 3.0 available so that EPA has access to the latest version of this model for evaluation of future Oil and Gas modeling submittals.

References

Nedwed, T.J., Smith, J.P., and M.G. Brandsma. 2004. Verification of the OOC Mud and Produced Water Discharge Model using lab-scale plume behavior experiments. Environmental Modelling & Software, Volume 19, Issues 7–8, July–August 2004, Pages 655-670.

Smith, J.P., Brandsma, M.G., and T.J. Nedwed. 2004. Field verification of the Offshore Operators Committee (OOC) Mud and Produced Water Discharge Model. Environmental Modelling & Software, Volume 19, Issues 7–8, July–August 2004, Pages 739-749

Attachment 1

**Drill Cuttings Modeling for Mud Line Cellar by Remotely Operate Vehicle (ROV)
Using EPA Contractor Input Data Files for Burger J Well**

DRILL CUTTINGS MODELING FOR MUD LINE CELLAR BY REMOTELY OPERATED VEHICLE (ROV)

USING EPA CONTRACTOR INPUT DATA FILES FOR BURGER J WELL

LOCATED OFFSHORE CHUKCHI SEA, ALASKA

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Report No. Burger_J_SO6_EPA_Contractor_InputData

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EXECUTIVE SUMMARY

This technical report describes the numeric simulations for two (2) input files obtained from EPA contractor Tetra Tech (Tt) for the water based drill cuttings discharges from the excavation of a Mud Line Cellar (**MLC**) using a subsea Remotely Operated Vehicle (**ROV**) for the prospect well **Burger J** located offshore Chukchi Sea. These two input files are **CASE-1.inp** and **CASE-2.inp**. Fluid Dynamix performed numerical simulations using the Offshore Operators Committee Mud and Produced Water Discharge Model (**OOC Model**), version **3.0**. The prospect well Burger J is located within the Burger Field offshore the Chukchi Sea. It is located in Block 6912 of area Posey. **Appendix A** lists the input files CASE-**1**.inp and CASE-**2**.inp**.** These input files represent the following discharge scenarios:

1. CASE-**2**.INP: Sea Floor Discharges (D013) for MLC ROV, Burger J at Mean Currents
   Water based drill cuttings discharges prior to the installation of the riser near the sea floor.

2. CASE-**1**.INP: Sea Floor Discharges (D013) for MLC ROV, Burger J at Maximum Currents
   Water based drill cuttings discharges prior to the installation of the riser near the sea floor.

CASE-**2**.inp (mean currents) and CASE-**1**.inp (maximum currents) data files yield maximum deposit loadings of **3,198** kg/m^2 cm and **1,490** kg/m^2, respectively. These translate into maximum deposit thicknesses of **120.7** cm and **56.2** cm for CASE-**2**.inp and CASE-**1**.inp data files, respectively based on a porosity value of **0.0** for the water based drill cuttings. The sea floor areas affected by solids deposit thickness of **1** cm or larger are **4.590 and 3.437** ha for CASE-**2**.inp and CASE-**1**.inp data files, respectively. The total suspended solids (TSS) concentration varies from **530.9** mg/l at **100** m to **12.6** mg/l at **1** km, from the source for CASE-**2**.inp data file. The TSS concentration varies from **200.0** mg/l at **100** m to **12.5** mg/l at **1** km, from the source for CASE-**1**.inp data file.

A comparison between the OOC model version **2.5** (release date: **12/2/1999**) and version **3.0** (release date: **12/26/2013**) predictions for CASE-**2**.inp and CASE-**1**.inp input files for the solids deposition on the seabed indicates that the OOC model version **3.0** predicts larger maximum solids deposit loading on the sea floor. A larger solids deposit loading yields higher deposit thickness.

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

TABLE OF ACRONYMS

bbls	Barrels
bbls/hour	Barrels per hour
cc	Cubic centimeter
cm	Centimeters
cm/sec	Centimeters per second
°C	Degrees Celsius
ft	Feet
g	Grams
g/cc	Grams per cubic centimeter
gal	Gallons
h	Hours
ha	Hectares
kg	Kilograms
kg/m^2	Kilograms per square meter
kg/m^3	Kilograms per cubic meter
km	Kilometers
lb	Pounds
lb/gal	Pounds per gallon
m	Meters
m/s	Meters per second
mg	Milligrams
mg/l	Milligrams per liter
MLC	Mud line cellar
psu	Practical salinity scale unit
ROV	Remotely operated vehicle
sec	Seconds
TSS	Total suspended solids

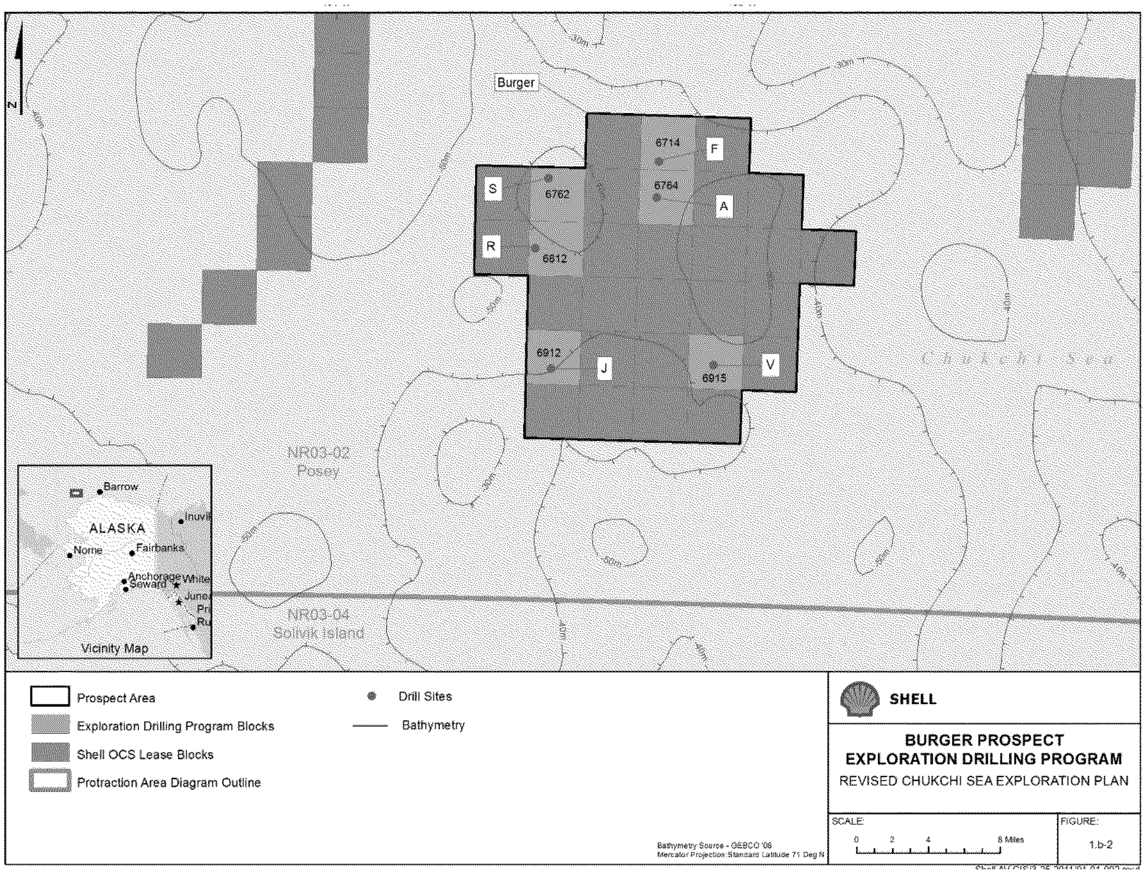
SECTION 1.0 I NTRODUCTION

This technical report describes the numeric simulations for two (2) input files obtained from EPA contractor Tetra Tech (Tt) for the water based drill cuttings discharges from the excavation of a Mud Line Cellar (**MLC**) using a subsea Remotely Operated Vehicle (**ROV**) for the prospect well **Burger J** located offshore Chukchi Sea. These two input files are **CASE-1.inp** and **CASE-2.inp**. Performed numerical simulations using the Offshore Operators Committee Mud and Produced Water Discharge Model (**OOC Model**), version **3.0**. The location of the well Burger J, within the Burger Field offshore the Chukchi Sea is presented in **Figure 1-1**. It is located in Block 6912 of area Posey. **Appendix A** lists the input files CASE-**1.**inp and CASE-**2.**inp**.** The input files represent the following discharge scenarios:

1. **CASE-2.INP**: **Sea Floor Discharges (D013) for MLC ROV, Burger J at Mean Currents**
   Water based drill cuttings discharges prior to the installation of the riser near the sea floor.

2. **CASE-1.INP: Sea Floor Discharges (D013) for MLC ROV, Burger J at Maximum Currents**
   Water based drill cuttings discharges prior to the installation of the riser near the sea floor.

Figure 1-1: Location of the Burger Field
Prospect Well: Burger J



SECTION 2.0 AMBIENT CHARACTERISTICS

This section describes the ambient characteristics data used in the CASE-**2**.inp and CASE-**1**.inp files.

2.1 DEPTH OF WATER

The CASE-**2**.inp and CASE-**1**.inp files used **44.0** m (or **144.35** feet) as the ambient water depth.

2.2 TEMPERATURE, SALINITY, AND CURRENT SPEED

The ambient water temperatures at the surface stratum and at bottom stratum were set to **0** degree Celsius (°C) in both the CASE-**2**.inp and CASE-**1**.inp files. The ambient water salinities at the surface stratum and at bottom stratum were set to **32** Practical Salinity Scale Unit (psu) in both the CASE-**2**.inp and CASE-**1**.inp files. The CASE-**2**.inp file used a current speed of **7** cm/sec (mean currents) and the CASE-**1**.inp file used a current speed of **25** cm/sec (maximum currents). **Table 2-1** lists the temperature, salinity, and currents speed data used in the CASE-**2**.inp and CASE-**1**.inp files.

Table 2-1: Ambient water characteristics for the Burger field, EPA contractor Data

Water Depth	Temperature	Salinity	Mean Current Speed	Maximum Current Speed	Current Direction
m	°C	psu	cm/s	cm/s	
0	0	32	7	25	to the East
44.0	0	32	7	25	to the East

2.4 WINDS SPEED AND WAVE HEIGHT

The wind speed and wave height were set to **0.0** m/s and **0.03** m (or **0.1** feet), respectively in both the CASE-**2**.inp and CASE-**1**.inp files.

Section 3.0 Effluent Characteristics

This section describes the effluent characteristics data used in the CASE-2.inp and CASE-1.inp files.

3.1 Discharge Data

Table 3-1 lists the discharge data for the CASE-**2**.inp and CASE-**1**.inp files. The pre-diluted effluent discharge rate is **13,529** bbls/hour in both the CASE-**2**.inp and CASE-**1**.inp files. The discharge duration is **604,800** seconds (or **7** days) in these the two input files. The CASE-**2**.inp file uses a **14,400** seconds (or **4** hours) and CASE-**1**.inp file uses a **7,200** seconds (or **2** hours) model time step.

Table 3-1: Discharge data for CASE-2.inp and CASE-1.inp files

Discharge Scenario	Input File Name	Durations of Drilling (Pumping)	Model Simulation	Model Time Step	Total Water Based Drill Cuttings including 50% Washout	Effluent Discharge Rate	Seawater Added to Effluent	Total Pre-diluted Effluent (water based drill cuttings + drilling fluids + seawater)	Pre-diluted Effluent Discharge Rate
		(sec)	(sec)	(sec)	(bbls)	(bbls/hour)	(bbls)	(bbls)	(bbls/hour)
MLC ROV	CASE-2.inp	604,800	604,800	14,400	27,197.03	161.89	2,245,603	2,272,800	13,529
MLC ROV	CASE-1.inp	604,800	604,800	7,200	27,197.03	161.89	2,245,603	2,272,800	13,529

3.3 Discharge Pipe and Height

The sea floor discharges occur from a **16.0**-inch internal diameter discharge pipe at **2.44** m (or **8.0** feet) above the sea floor for both the CASE-**2**.inp and CASE-**1**.inp files.

3.4 Fall Velocity Classes for Water Based Drill Cuttings

The fall velocity classes and volume fractions for water based drill cuttings in both theCASE-**2**.inp and CASE-**1**.inp files are approximately the same data presented in the OOC model Report and User Guide (Brandsma and Smith, **1999**) for the water based mud cuttings. **Table 3-2** presents the fall velocity classes and volume fractions for water based drill cuttings used in these two input files. The solids density is **2.65** g/cc in these the two input files as listed in **Table 3-2**. EPA contractor Tt used a value of **1.0** for ASFM (MAXIMUM ENHANCED SETTLING FACTOR). Fluid Dynamix performed the numeric simulations for CASE-**2**.inp and CASE-**1**.inp using ASFM = **1.0** as well. The recommended value for ASFM is **28.0** (Page 4-10, Report and User Guide, Brandsma and Smith, **1999**).

Table 3-2: Fall velocity classes and volume fractions for water based drill cuttings

Well ID	Sediment Class in Drill Cuttings	Solids Density	Fall Velocity		Volume Fractions
		(g/cc)	(ft/sec)	(cm/s)	
MLC ROV, Burger J	1	2.65	0.000003	0.00009144	0.0009573
	2		0.000047	0.00143256	0.0007180
	3		0.000664	0.02023872	0.0008376
	4		0.007383	0.22503384	0.0003590
	5		0.03868	1.1789664	0.0002393
	6		0.115392	3.51714816	0.0021539
	7		0.236888	7.22034624	0.0019146
	8		0.459383	14.0019938	0.0017949
	9		0.871619	26.5669471	0.0029916

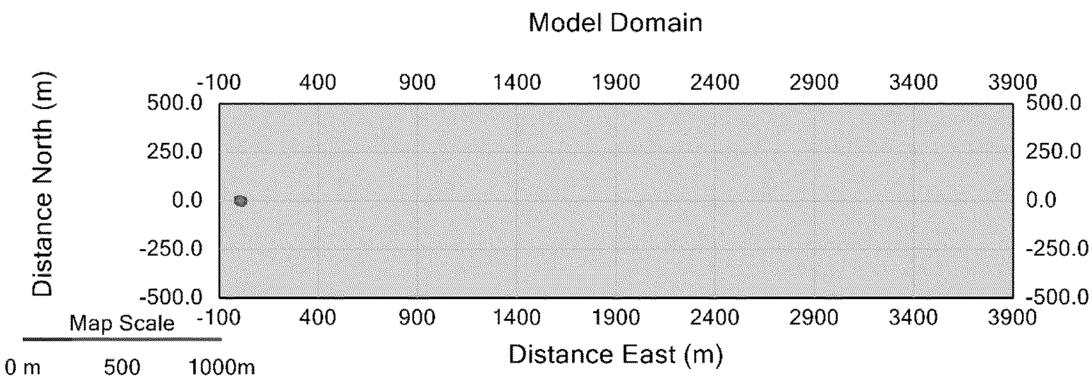
3.5 Effluent Density

The effluent bulk density was set to **8.72** pounds/gallons (or **1,045.20** kg/m^3) in both the CASE-**2**.inp and CASE-**1**.inp files.

SECTION 4.0 MODEL DOMAIN

The model domain extends to **4,000** m (**4** km) in the west-east direction and **1,000** m (**1** km) in the north-south direction. The model consists of **200** cells in the west-east direction and **50** cells in the north-south direction. Each cell is a **20** m × **20** m square. The well is located at **100** m to the east from the west boundary and **500** m to the south from the north boundary of the model domain as shown by a blue dot in **Figure 4-1**.

Figure 4-1: Model domain for CASE-2.inp and CASE-1.inp files for MLC ROV, Burger J simulation



SECTION 5.0 DISPERSION AND DEPOSITION MODELING – CASE-2.INP

This section describes the numeric simulation for CASE-**2**.inp file obtained from EPA contractor Tetra Tech (Tt) for the water based drill cuttings discharges from the excavation of a Mud Line Cellar (**MLC**) using a subsea ROV for the prospect well Burger J located offshore Chukchi Sea. Performed the numerical simulation using the OOC Model, version **3.0** for a drilling duration of **604,800** sec (or **7** days) using a **14,400**-sec (or **4** hours) model time step. This section presents the OOC model predicted trajectory and shape of the discharge plume; total suspended solids (TSS) concentrations in the water column; and the total solids deposition loading. Moreover, this section also presents the GUIDO **7** (Alam and Brandsma, **2013**) predicted solids deposit thickness distribution on the seabed using a porosity of **0.0** for the drill cuttings. Tt used a porosity of **0.0** for the drill cuttings to compute the solids deposit thickness from the mass deposition loading values.

TRAJECTORY AND SHAPE OF THE DISCHARGE PLUME

Figure 5-1 presents the trajectory of the discharge plume. The depth of water is **44.0** m and the discharge occurs at a depth of **41.56** m from a **16.0** inches internal diameter discharge pipe of the sea floor pump at **13,529** bbls/hour. The discharge pipe is located at **2.44** m (or **8** feet) above the seafloor and oriented horizontally aligned with the direction of the current, which is to the east. Therefore, the heavier discharge plume attempts to shoot horizontally as seen in Figure **5-1**. It travels to the east to a distance approximately **0.45** m only from the source before collapsing onto the sea floor due to the low mean currents of **7** cm/s and the proximity of the plume near the sea floor. **Figure 5-2** presents the shape and width of the discharge plume. The width of the plume is approximately **0.45** m at a distance **0.45** m from the source. The solid lines present the outer boundaries and dotted line presents the centerline of the discharge plume in Figures **5-1** and **5-2**.

Figure 5-1: Trajectory of the discharge plume for CASE-2.inp

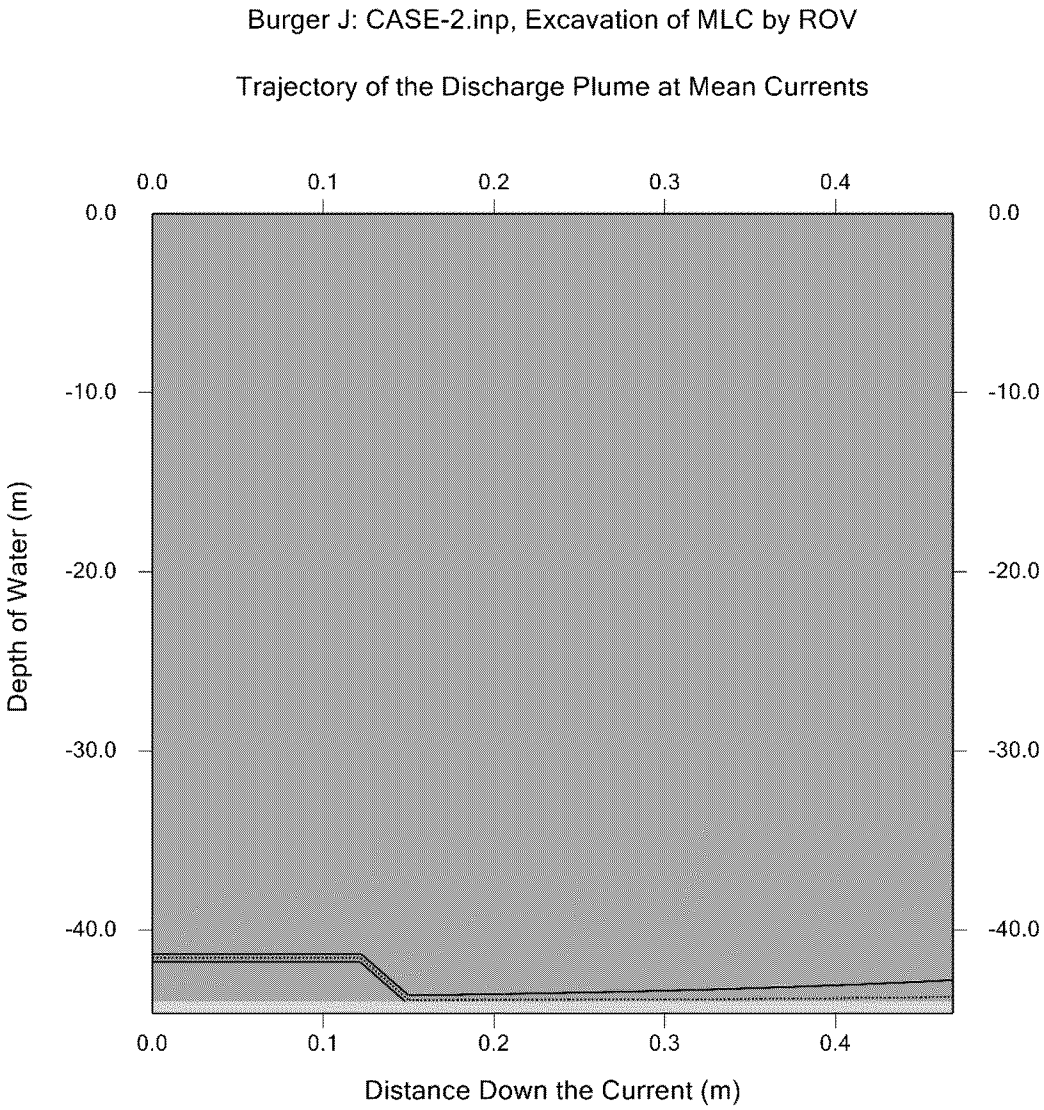
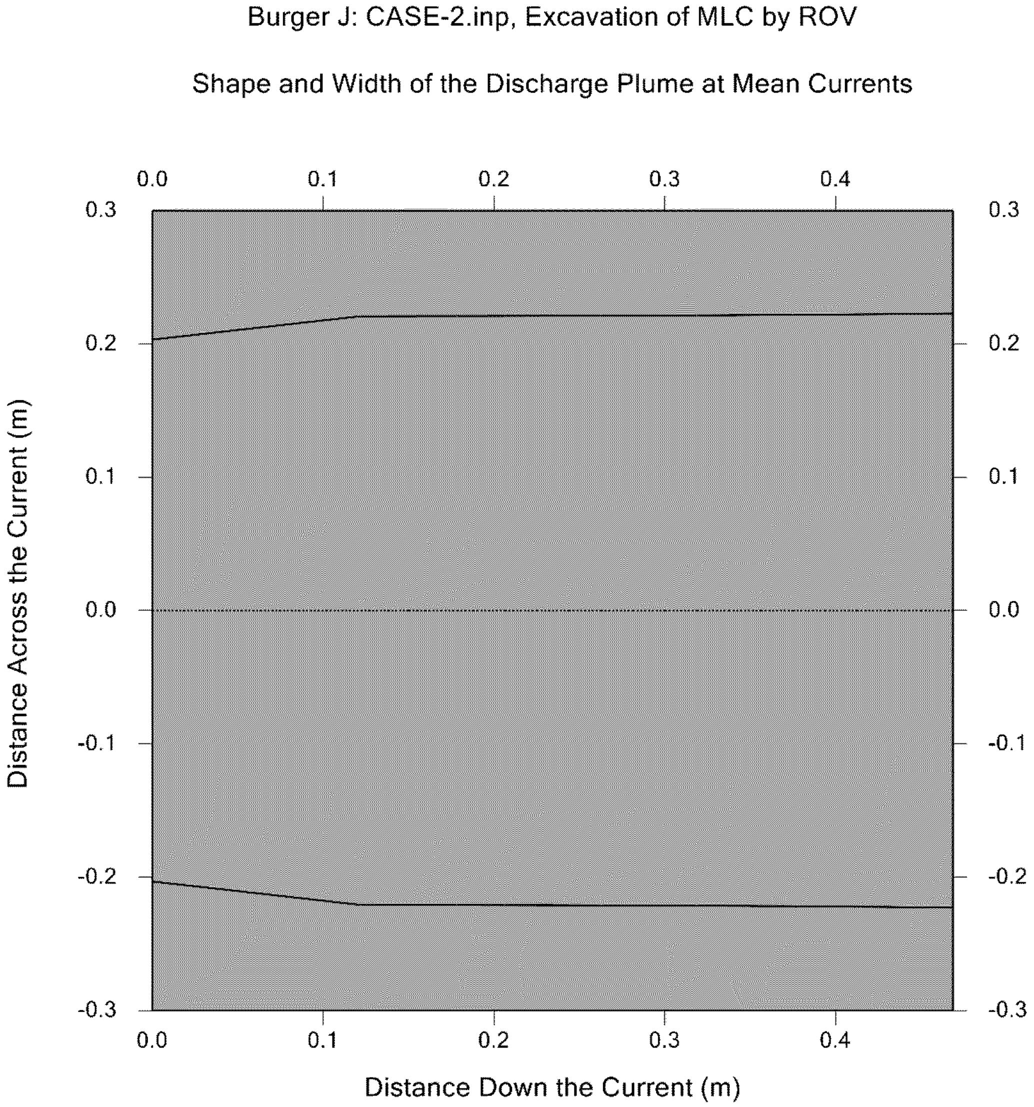


Figure 5-2: Shape and width of the discharge plume for CASE-2.inp

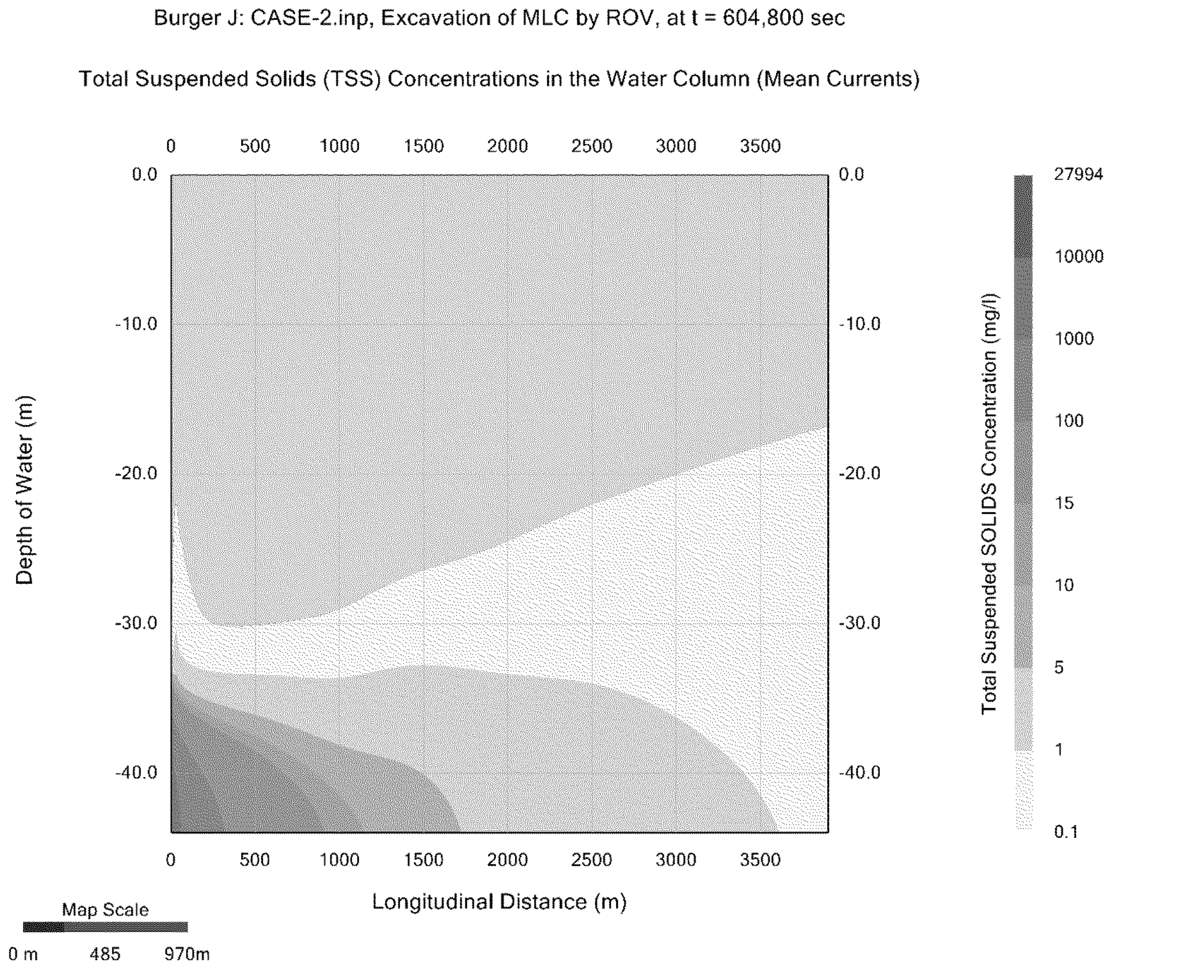


Total Suspended Solids (TSS) Concentrations in the Water Column

Figure 5-3 presents the total suspended solids (TSS) concentrations in the water column at time, t =**604,800** sec (or **7.0** days) which is the discharge duration for this drill interval. The depth of water is**44.0** m at the discharge location. The discharge occurs at a depth of **41.56** m from a **16.0** inches internal diameter discharge pipe. The color-filled contours present the variations of the TSS concentrations both with respect to the depth from the sea surface and the distance from the source by different color bands. The maximum TSS concentration**27,994** mg/l occurs at the discharge location. It decreases to a value of **100** mg/l and **15** mg/l at distances approximately **320** m and **900** m, respectively from the discharge location. It varies from **15** to **10** mg/l approximately between **900** and **1,150** m distances from the discharge location. It varies from **10** to **5** mg/l between **1,150** and **1,725** m distances from the source. It varies from **5** to **1** mg/l between **1,725** and **3,600** m distances from the source. It is less than **1** mg/l beyond **3,600** m from the discharge location. The effect of the sea floor pump is visible in this Figure**5-3**. The discharge plume is spreading farther horizontally to the east along the direction of the current than vertically. The TSS concentration is less than **1** mg/l at a depth approximately **30** m at or near the discharge location. It is less than **10** mg/l at a depth **40** m at **1,000** m from the discharge location.

The maximum TSS concentrations at **10**-, **30**-, **100**-, **300**-, and **1000**-m from the discharge location are: **4,589.9**, **1,884.6**, **530.9**, **109.3** and **12.6** mg/l, respectively.

Figure 5-3: Total suspended solids concentrations in water column for CASE-2.inp



AMOUNT OF DEPOSITION OF THE DISCHARGED SOLIDS ON THE SEABED

The spatial extent and the amount of solids loading on the sea floor at time, t =**604,800** sec (or **168.0** hours) as a result of the discharge of the water based drill cuttings on a plan view is presentedin **Figures 5-4a** and **5-4b**. The well is located at the origin (**0**, **0**) of these figures. The model domain extends to **4.0** km in the currents direction and **1.0** km across the currents direction from the discharge location as shown in Figure **5-4a**. A zoom in view of the model results, which shows only **2.0** km x **0.5** km area of the seabed is presented in Figure **5-4**b. The map scale is located at the bottom left corner of these figures. The color bar on the right provides the range of the solids loading on the sea floor in **kg/m²** by a particular color band. The maximum loading **3,198** kg/m² occurs at **10** m to the east and **10** m to the south from the discharge location. It decreases to a value of **100** kg/m² and **30** kg/m² at distances approximately **120** m and **250** m, respectively from the discharge location as shown in Figure **5-4**b. It varies from **30** kg/m² to **10** kg/m² between distances approximately **250** m and **480** m, respectively from the discharge location. It varies from **10** kg/m² to **3** kg/m² between distances approximately **480** m and **750** m, respectively from the discharge location. It varies from **3** kg/m² to **1** kg/m² approximately between **750** and **950** m distances from the discharge location. It varies from **1** kg/m² to **0.3** kg/m² approximately between **950** and **1,125** m distances from the discharge location. It varies from **0.3** kg/m² to **0.1** kg/m² approximately between **1,125** and **1,550** m distances from the discharge location. The loading is less than **0.1** kg/m² beyond **1,550** m from the discharge location.

The sea floor areas affected by solids deposit loading of more than **1000**-, **100**-, **10**-, **1**-, and **0.1**-kg/m² are: **0.191**, **1.825**, **8.192**, **25.317**, and **64.271** hectares (ha), respectively.

Figure 5-4a: Amount of deposition of the solids on the seabed for CASE-2.inp, full view

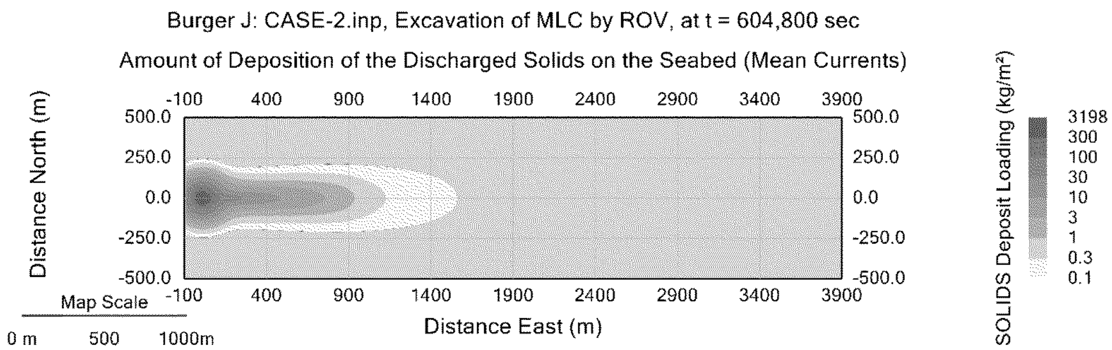
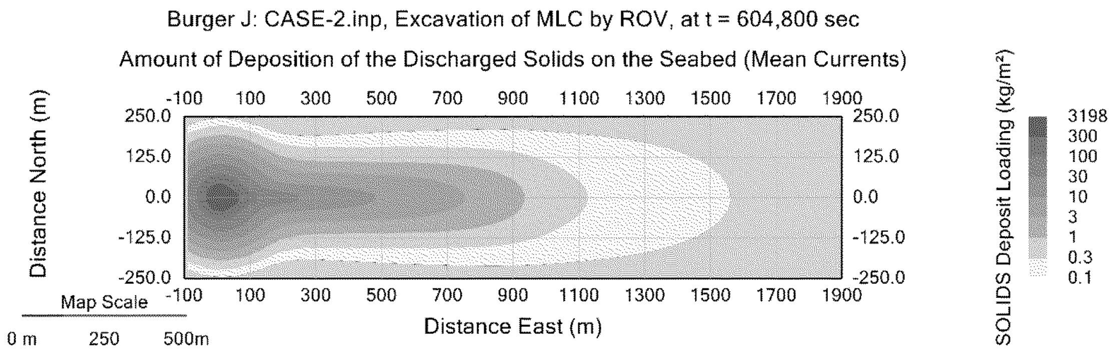


Figure 5-4b: Amount of deposition of the solids on the seabed for CASE-2.inp, zoom view



SPATIAL EXTENT OF SOLIDS THICKNESS DISTRIBUTION ON THE SEABED

The spatial extent of solids thickness of **1** cm or larger deposited on the sea floor at time, t = **604,800** sec (or **168.0** hours) as a result of the discharge of the water based drill cuttings on a plan view is presented in **Figures 5-5a** and **5-5b.** The well is located at the origin (**0**, **0**) of these figures. The model domain extends to **4.0** km in the currents direction and **1.0** km across the currents direction from the discharge location as shown in Figure **5-5a**. A zoom in view of the model results, which shows only **2.0** km x **0.5** km area of the seabed is presented in Figure **5-4b**. The map scale is located at the bottom left corner of these figures. The color bar on the right provides the range of the solids deposit thickness on the sea floor in **cm** by a particular color band. The maximum deposit thickness of **120.7** cm occurs at **10** m to the east and **10** m to the south from the discharge location. It decreases to a value of **100** cm at a distance approximately **20** m from the discharge location as shown in Figure **5-5**b. It decreases: **100** cm to **30** cm between **20** m and **40** m; **30** cm to **10** cm between **40** m and **70** m; **10** cm to **3** cm between **70** m and **130** m; and **3** cm to **1** cm between **130** m and **275** m distances approximately from the discharge location. It is less than **1** cm beyond **275** m approximately to the east from the discharge location.

The sea floor areas affected by deposit thickness larger than **100**-, **10**-, and **1**-cm are: **0.091**, **0.673**, and **4.590** ha, respectively. **Figure 5-6** presents the sea floor area affected by solids thickness distribution for CASE-**2**.inp file.

Figure 5-5a: Spatial extent of solids thickness distribution on seabed for CASE-2.inp, full view

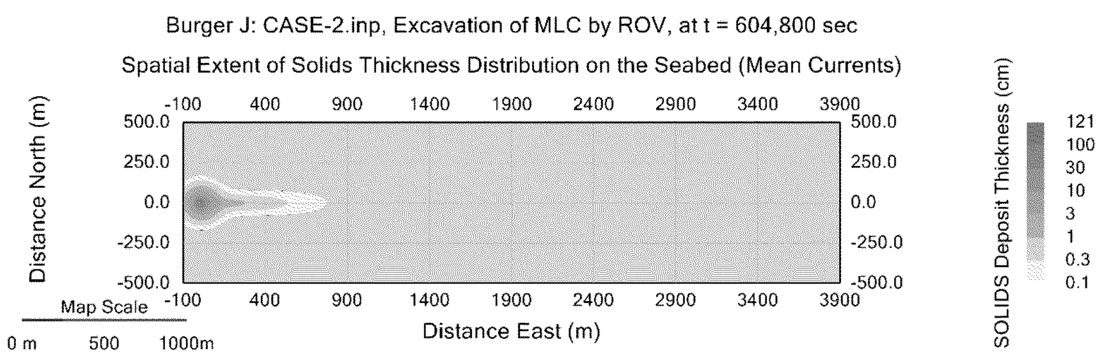


Figure 5-5b: Spatial extent of solids thickness distribution on seabed for CASE-2.inp, zoom view

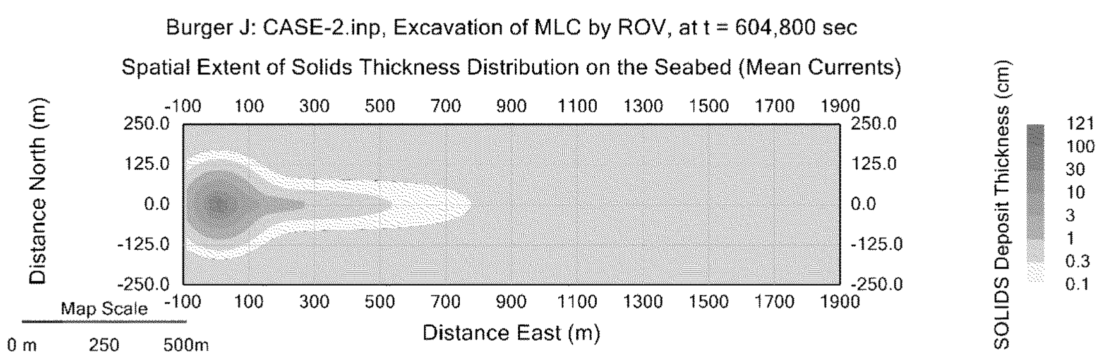


Figure 5-6: Sea floor area affected by solids thickness distribution for CASE-2.inp

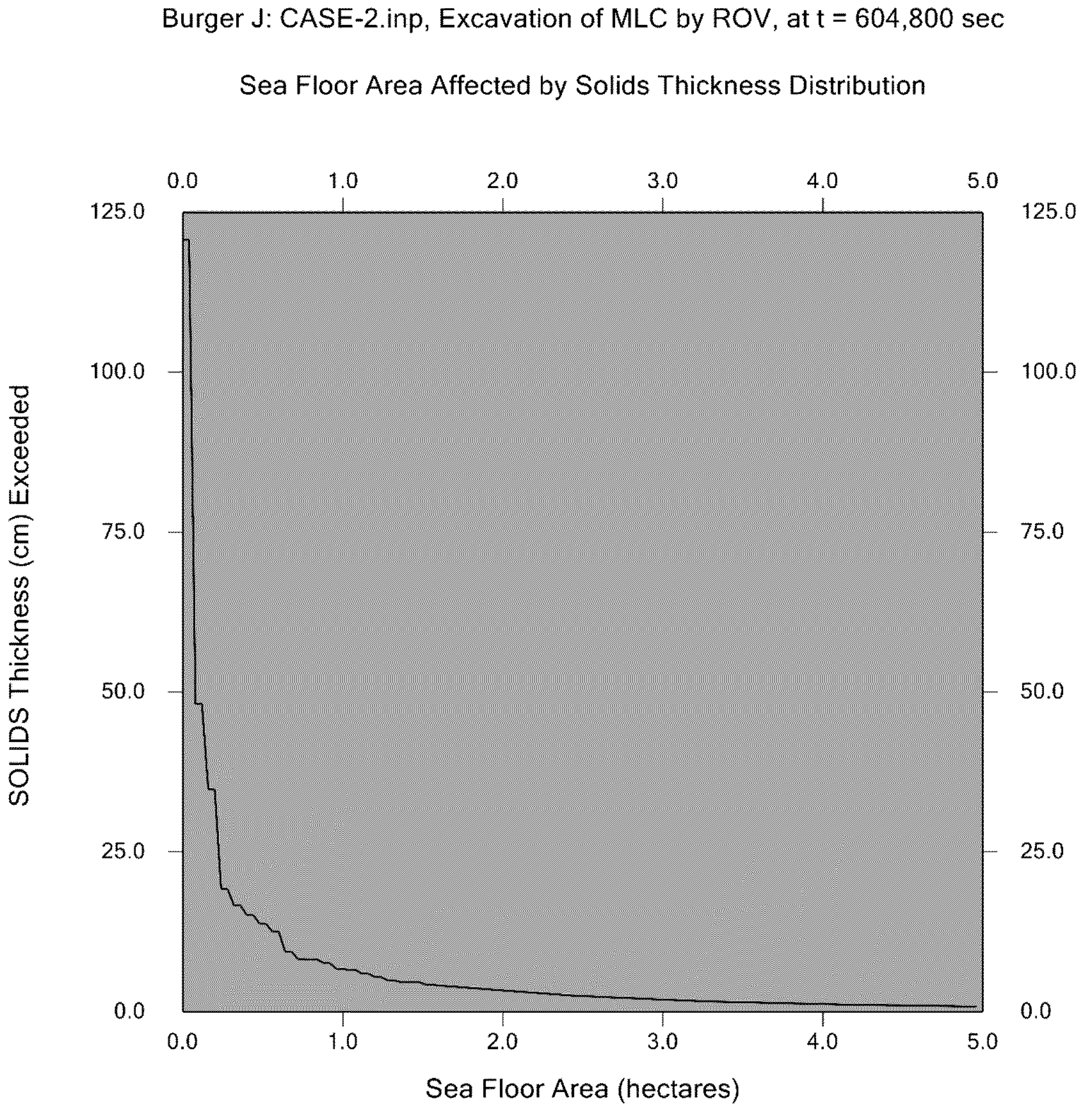


Table 5-1 presents the OOC model predictions for CASE-2.inp input file for the solids deposition on the seabed and the TSS concentrations.

Table 5-1: Summary Model Results - Sea Floor Discharges at Mean Currents (CASE-2.inp)

The OOC (version 3.0) Model Predictions						CASE-2.inp (Mean Currents)							
Discharge Scenario	Drilling Intervals	Durations of Discharge	Depth of Water	Depth of Discharge	Pre-diluted Effluent Discharge Rate	Solids Deposition on the Seabed				Total Suspended Solids (TSS) Concentration in Water Column - (distances from the source)		
						Maximum Loading	Area Covered by Solids Thickness (ha)		Maximum Deposit Thickness	100 m	300 m	1 km
		sec	m	m	bbls/hour	kg/m^2	> 10 cm	> 1 cm	cm	mg/l	mg/l	mg/l
Sea Floor	MLC ROV	604,800	44.0	41.56	13,529	3,198	0.673	4.590	120.7	530.9	109.3	12.6

Section 6.0 Dispersion and Deposition Modeling – CASE-1.inp

This section describes the numeric simulation for CASE-**1**.inp file obtained from EPA contractor Tetra Tech (Tt) for the water based drill cuttings discharges from the excavation of a Mud Line Cellar (**MLC**) using a subsea ROV for the prospect well Burger J located offshore Chukchi Sea. Performed the numerical simulation using the OOC Model, version **3.0** for a drilling duration of **604,800** sec (or **7** days) using a **7,200**-sec (or **2** hours) model time step. This section presents the OOC model predicted trajectory and shape of the discharge plume; total suspended solids (TSS) concentrations in the water column; and the total solids deposition loading. Moreover, this section also presents the GUIDO **7** (Alam and Brandsma, **2013**) predicted solids deposit thickness distribution on the seabed using a porosity of **0.0** for the drill cuttings**.** Tt used a porosity of **0.0** for the drill cuttings to compute the solids deposit thickness from the mass deposition loading values.

TRAJECTORY AND SHAPE OF THE DISCHARGE PLUME

Figure 6-1 presents the trajectory of the discharge plume. The depth of water is **44.0** m and the discharge occurs at a depth of **41.56** m from a **16.0** inches internal diameter discharge pipe of the sea floor pump at **13,529** bbls/hour. The discharge pipe is located at **2.44** m (or **8** feet) above the seafloor and oriented horizontally aligned with the direction of the current, which is to the east. Therefore, the heavier discharge plume attempts to shoot horizontally as seen in Figure **6-1**. It travels to the east to a distance approximately **40** m from the source before collapsing onto the sea floor due to the proximity of the plume near the sea floor. **Figure 6-2** presents the shape and width of the discharge plume. The width of the plume is approximately **8.5** m at a distance **40** m from the source. The solid lines present the outer boundaries and dotted line presents the centerline of the discharge plume in Figures **6-1** and **6-2**. The lower boundary of the discharge plume scours and penetrates the sea floor at a distance approximately **13** m from the discharge location. Therefore, Figure **6-1** does not contain the lower boundary of the discharge plume beyond **13** m from the source.

Figure 6-1: Trajectory of the discharge plume for CASE-1.inp

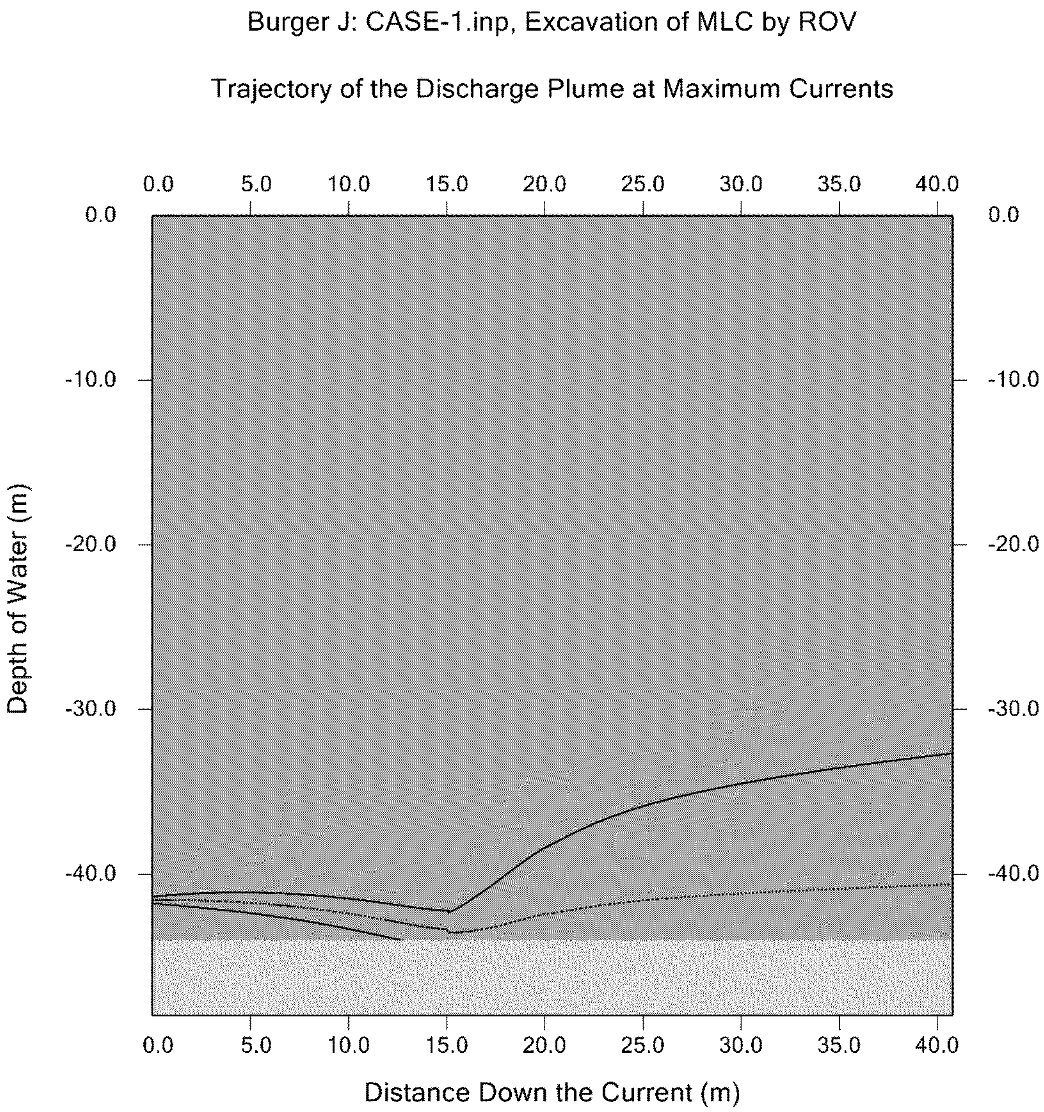
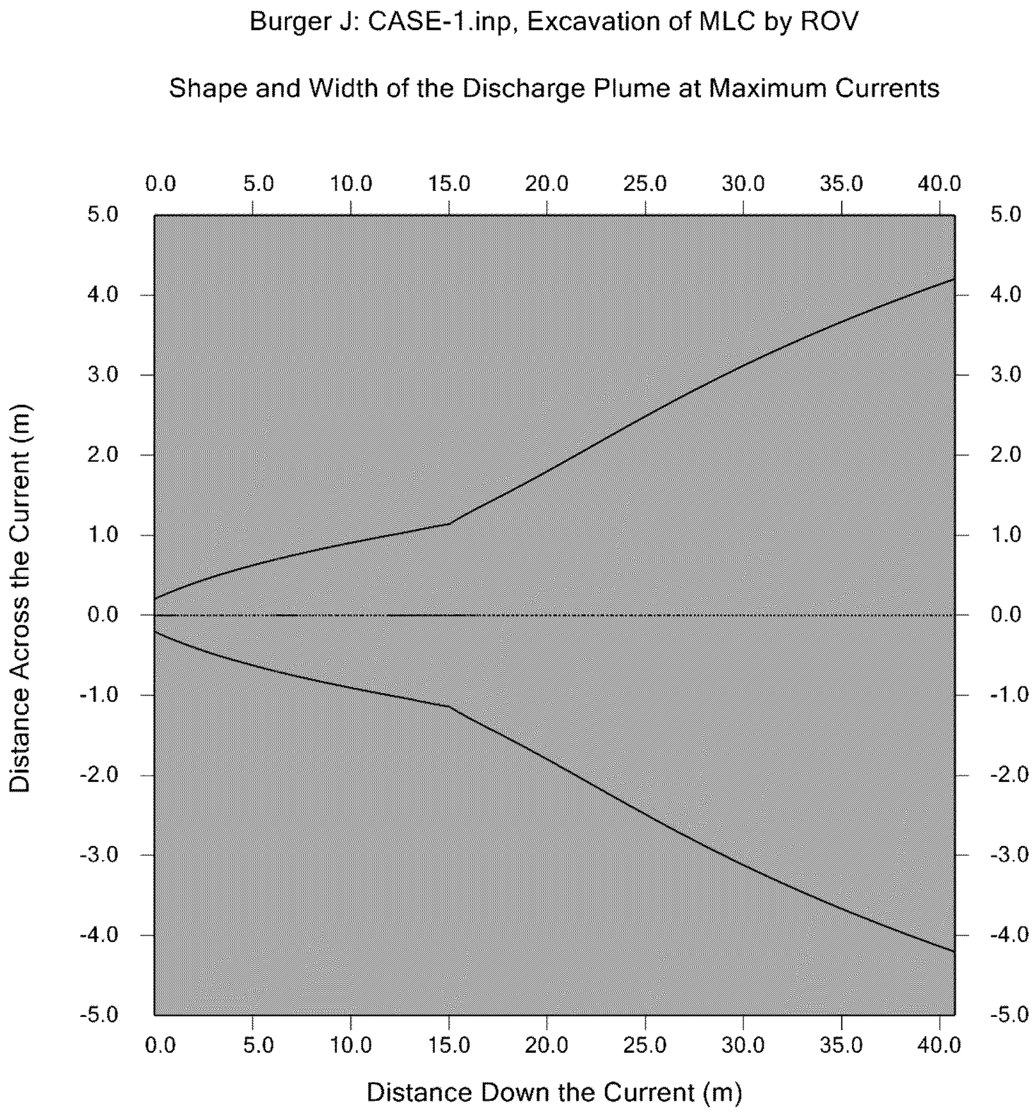


Figure 6-2: Shape and width of the discharge plume for CASE-1.inp

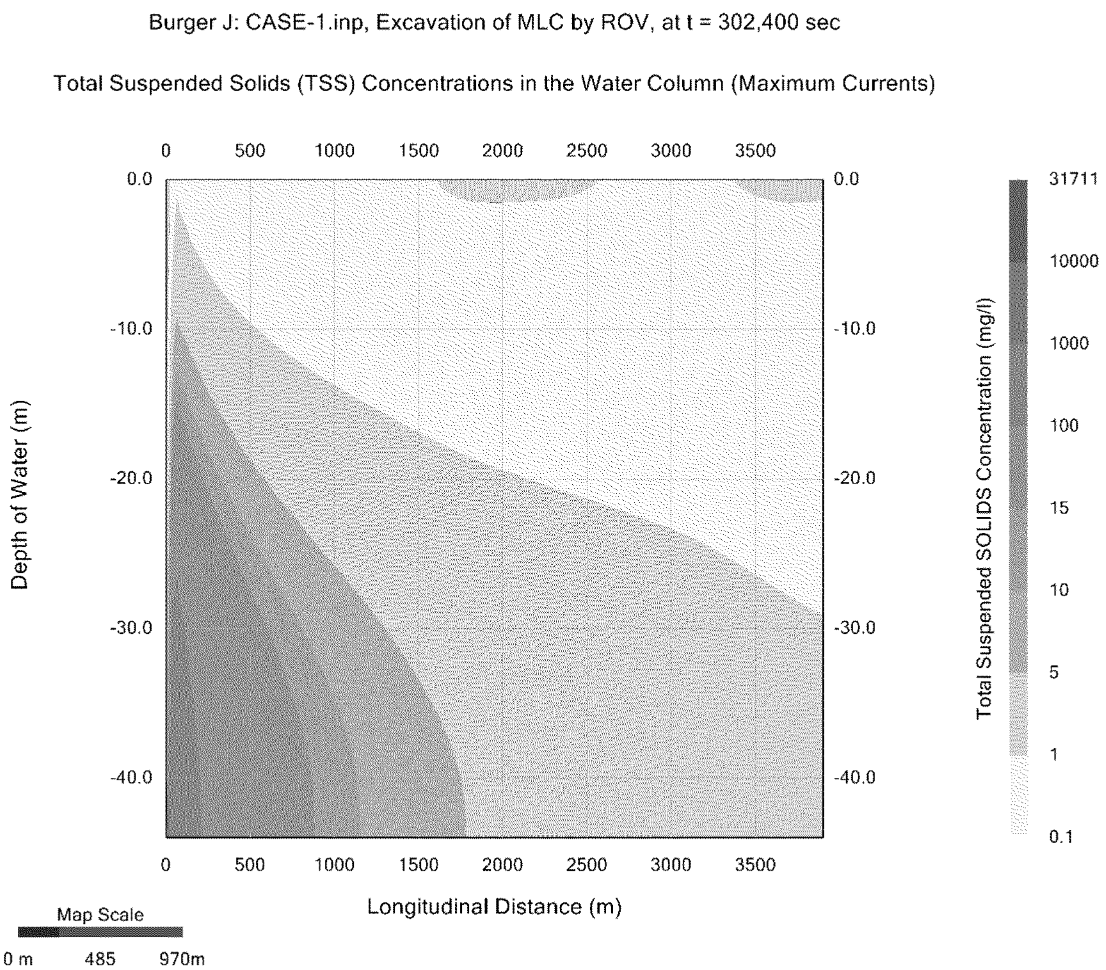


Total Suspended Solids (TSS) Concentrations in the Water Column

Figure 6-3 presents the total suspended solids (TSS) concentrations in the water column at time, t =**302,400** sec (or **3.5** days). The OOC model exhibits numerical oscillations in TSS concentrations computation after time t = **302,400** sec. However, steady state conditions has reached before this time. Therefore, this presents the maximum TSS values in the modeling domain. The depth of water is**44.0** m at the discharge location. The discharge occurs at a depth of **41.56** m from a **16.0** inches internal diameter discharge pipe. The color-filled contours present the variations of the TSS concentrations both with respect to the depth from the sea surface and the distance from the source by different color bands. The maximum TSS concentration**31,711** mg/l occurs at the discharge location. It decreases to a value of **100** mg/l and **15** mg/l at distances approximately **200** m and **900** m, respectively from the discharge location. It varies from **15** to **10** mg/l approximately between **900** and **1,150** m distances from the discharge location. It varies from **10** to **5** mg/l between **1,150** and **1,800** m distances from the source. It is less than **5** mg/l beyond **1,800** m from the discharge location. The effect of the maximum currents speed is visible in the enhanced mixing of the effluent within the entire depth of the water column as shown in this Figure **6-3**.

The maximum TSS concentrations at **10-**, **30-**, **100-**, **300-**, and **1000**-m from the discharge location are **10,000.0**, **250.0**, **200.0**, **65.0,** and **12.5** mg/l, respectively.

Figure 6-3: Total suspended solids concentrations in water column for CASE-1.inp



AMOUNT OF DEPOSITION OF THE DISCHARGED SOLIDS ON THE SEABED

The spatial extent and the amount of solids loading on the sea floor at time, t= **604,800** sec (or **168.0** hours) as a result of the discharge of the water based drill cuttings on a plan view is presentedin **Figures 6-4a** and **6-4b**. The well is located at the origin (**0**, **0**) of these figures. The model domain extends to **4.0** km in the currents direction and **1.0** km across the currents direction from the discharge location as shown in Figure **6-4a**. A zoom in view of the model results, which shows only **2.0** km x **0.5** km area of the seabed is presented in Figure **6-4**b. The map scale is located at the bottom left corner of these figures. The color bar on the right provides the range of the solids loading on the sea floor in **kg/m^2** by a particular color band. The maximum loading **1,490** kg/m^2 occurs at **50** m to the east and **10** m to the south from the discharge location. It decreases to a value of **100** kg/m^2 and **30** kg/m^2 at distances approximately **300** m and **480** m, respectively from the discharge location as shown in Figure **6-4**b. It varies from **30** kg/m^2 to **10** kg/m^2 between distances approximately **480** m and **950** m, respectively from the discharge location. It varies from **10** kg/m^2 to **3** kg/m^2 between distances approximately **950** m and **1,500** m, respectively from the discharge location. It varies from **3** kg/m^2 to **1** kg/m^2 approximately between **1,500** and **1,800** m distances from the discharge location. It varies from **1** kg/m^2 to **0.3** kg/m^2 approximately between **1,800** and **2,500** m distances from the discharge location. The loading is less than **0.3** kg/m^2 beyond **2,500** m from the discharge location.

The sea floor areas affected by solids deposit loading of more than **1000**-, **100**-, **10**-, **1**-, and **0.1**-kg/m^2 are: **0.342**, **1.710**, **6.396**, **17.434**, and **70.960** hectares (ha), respectively.

Figure 6-4a: Amount of deposition of the solids on the seabed for CASE-1.inp, full view

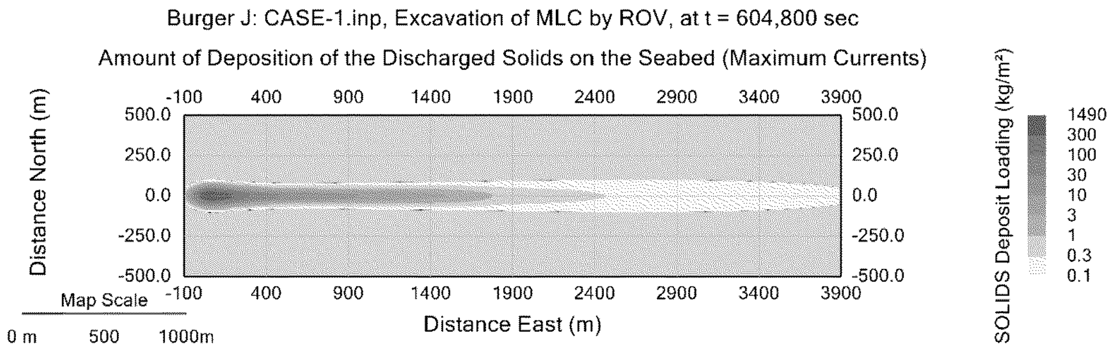
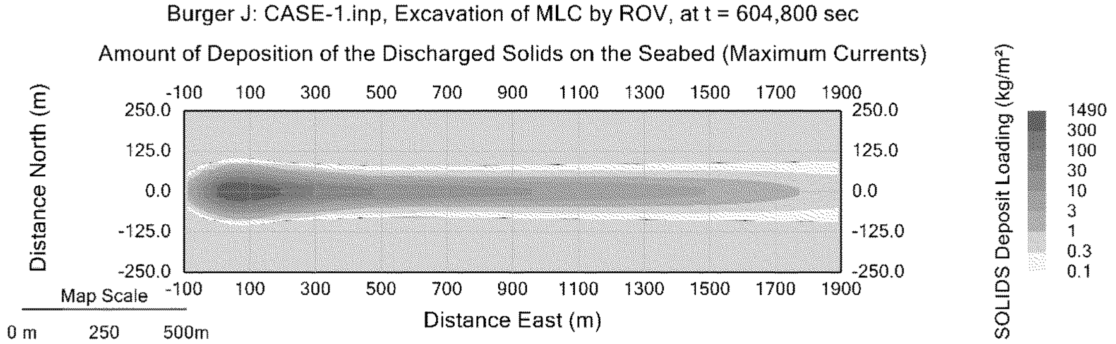


Figure 6-4b: Amount of deposition of the solids on the seabed for CASE-1.inp, zoom view



SPATIAL EXTENT OF SOLIDS THICKNESS DISTRIBUTION ON THE SEABED

The spatial extent of solids thickness of **1** cm or larger deposited on the sea floor at time, t = **604,800** sec (or **168.0** hours) as a result of the discharge of the water based drill cuttings on a plan view is presented in **Figures 6-5a** and **6-5b.** The well is located at the origin (**0**, **0**) of these figures. The model domain extends to **4.0** km in the currents direction and **1.0** km across the currents direction from the discharge location as shown in Figure **6-5a**. A zoom in view of the model results, which shows only **1.0** km x **0.25** km area of the seabed is presented in Figure **6-4b**. The map scale is located at the bottom left corner of these figures. The color bar on the right provides the range of the solids deposit thickness on the sea floor in **cm** by a particular color band. The maximum deposit thickness of **56.2** cm occurs at **50** m to the east and **10** m to the south from the discharge location. It decreases to a value of **30** cm at a distance approximately **125** m from the discharge location as shown in Figure **6-5**b. It decreases: **30** cm to **10** cm between **125** m and **200** m; **10** cm to **3** cm between **200** m and **325** m; and **3** cm to **1** cm between **325** m and **510** m distances approximately from the discharge location. It is less than **1** cm beyond **510** m approximately to the east from the discharge location.

The sea floor areas affected by deposit thickness larger than **10**- and **1**-cm are: **0.826** and **3.437** ha, respectively. **Figure 6-6** presents the sea floor area affected by solids thickness distribution for CASE-**1**.inp file.

Figure 6-5a: Spatial extent of solids thickness distribution on seabed for CASE-1.inp, full view

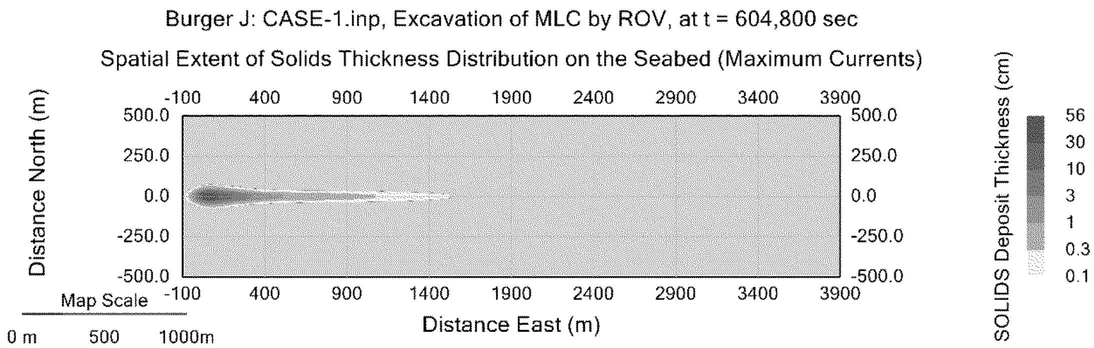


Figure 6-5b: Spatial extent of solids thickness distribution on seabed for CASE-1.inp, zoom view

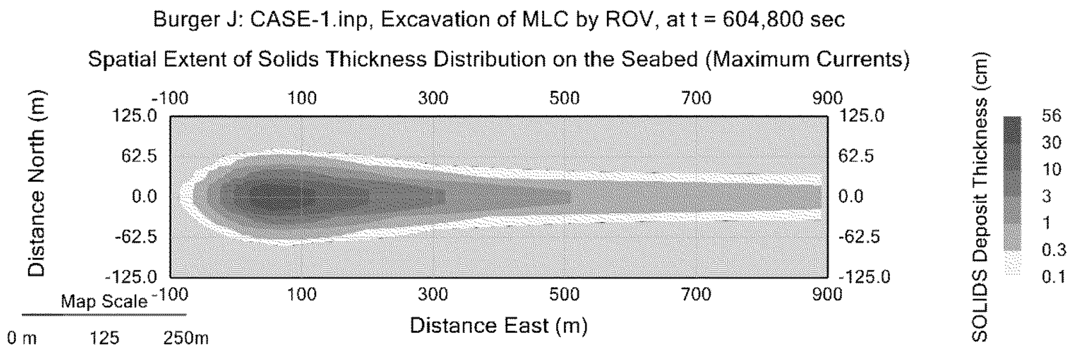


Figure 6-6: Sea floor area affected by solids thickness distribution for CASE-1.inp

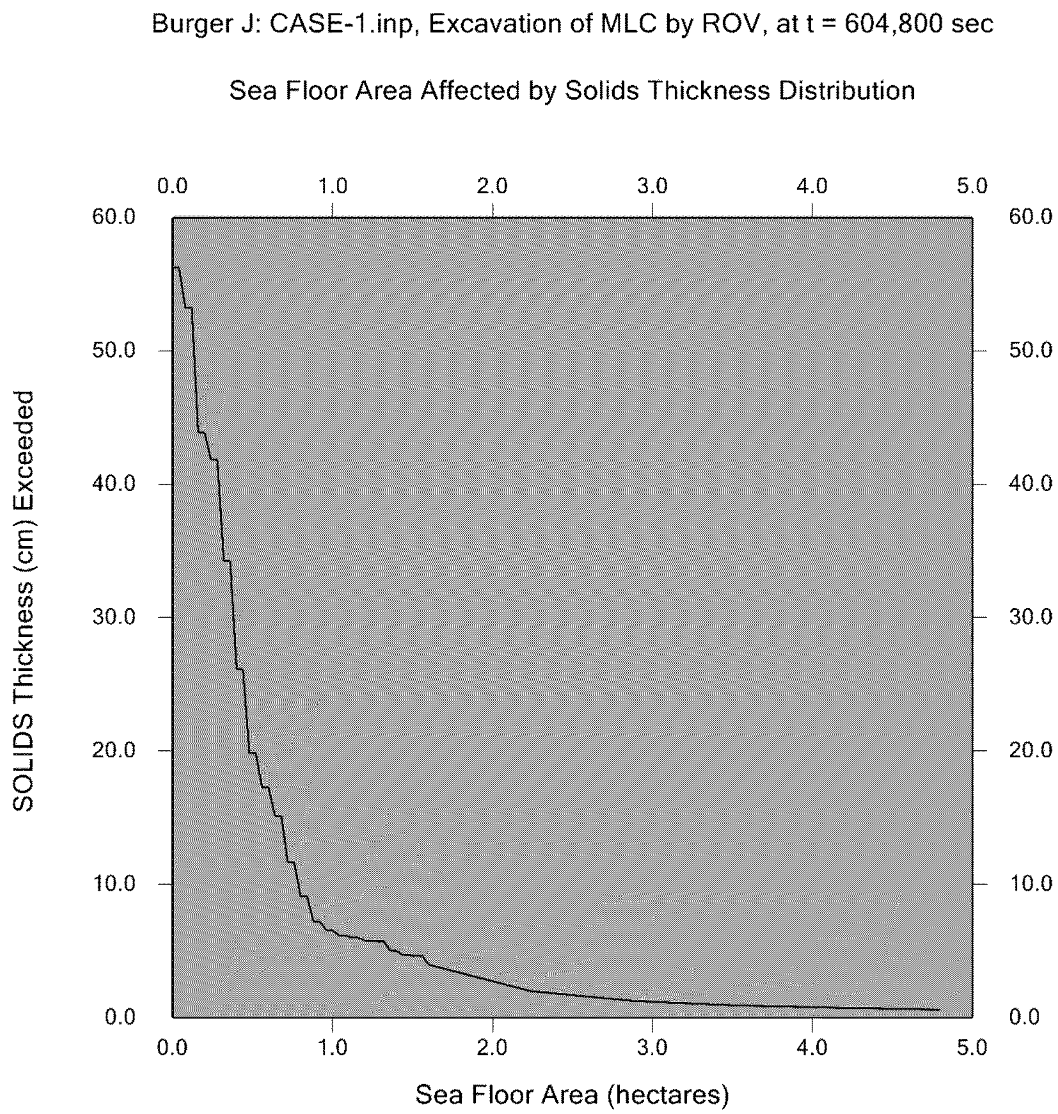


Table 6-1 presents the OOC model predictions for CASE-**1**.inp input file for the solids deposition on the seabed and the TSS concentrations.

Table 6-1: Summary Model Results - Sea Floor Discharges at Maximum Currents (CASE-1.inp)

The OOC (version 3.0) Model Predictions						CASE-1.inp (Maximum Currents)						
Discharge Scenario	Drilling Intervals	Durations of Discharge	Depth of Water	Depth of Discharge	Pre-diluted Effluent Discharge Rate	Solids Deposition on the Seabed				Total Suspended Solids (TSS) Concentration in Water Column - (distances from the source)		
						Maximum Loading	Area Covered by Solids Thickness (ha)		Maximum Deposit Thickness	100 m	300 m	1 km
		sec	m	m	bbls/hour	kg/m²	> 10 cm	> 1 cm	cm	mg/l	mg/l	mg/l
Sea Floor	MLC ROV	604,800	44.0	41.56	13,529	1,490	0.826	3.437	56.2	200.00	65.00	12.50

SECTION 7.0 SUMMARY AND CONCLUSION

This technical report describes the numeric simulations for two (**2**) input files obtained from EPA contractor Tetra Tech (Tt) for the water based drill cuttings discharges from the excavation of a Mud Line Cellar (**MLC**) using a subsea Remotely Operated Vehicle (**ROV**) for the prospect well **Burger J** located offshore Chukchi Sea. These two input files are **CASE-1.inp** and **CASE-2.inp**. Fluid Dynamix performed numerical simulations using the Offshore Operators Committee Mud and Produced Water Discharge Model (**OOC Model**), version **3.0**. The prospect well Burger J is located within the Burger Field offshore the Chukchi Sea. It is located in Block 6912 of area Posey. **Appendix A** lists the input files CASE-**1.**inp and CASE-**2.**inp**.** These input files represent the following discharge scenarios:

1. CASE-**2**.INP: Sea Floor Discharges (D013) for MLC ROV, Burger J at Mean Currents
   Water based drill cuttings discharges prior to the installation of the riser near the sea floor.

2. CASE-**1**.INP: Sea Floor Discharges (D013) for MLC ROV, Burger J at Maximum Currents
   Water based drill cuttings discharges prior to the installation of the riser near the sea floor.

Table 7-1 presents the OOC model predictions for CASE-**2**.inp and CASE-**1**.inp input files for the solids deposition on the seabed and the TSS concentrations. CASE-**2**.inp (mean currents) and CASE-**1**.inp (maximum currents) data files yield maximum deposit loadings of **3,198** kg/m^2 cm and **1,490** kg/m^2, respectively. These translate into maximum deposit thicknesses of **120.7** cm and **56.2** cm for CASE-**2**.inp and CASE-**1**.inp data files, respectively based on a porosity value of **0.0** for the water based drill cuttings. The sea floor areas affected by solids deposit thickness of **1** cm or larger are **4.590** and **3.437** ha for CASE-**2**.inp and CASE-**1**.inp data files, respectively. The total suspended solids (TSS) concentration varies from **530.9** mg/l at **100** m to **12.6** mg/l at **1** km, from the source for CASE-**2**.inp data file. The TSS concentration varies from **200.0** mg/l at **100** m to **12.5** mg/l at **1** km, from the source for CASE-**1**.inp data file.

Table 7-2 presents the OOC model version **2.5** (release date: **12/2/1999**) and version **3.0** (release date: **12/26/2013**) predictions for CASE-**2**.inp and CASE-**1**.inp input files for the solids deposition on the seabed. The OOC model version 3.0 predicts larger maximum solids deposit loading on the sea floor. A larger solids deposit loading yields higher deposit thickness.

Table 7-1: Summary Model Results – CASE-2.inp and CASE-1.inp files, MLC ROV, Burger J

The OOC (version 3.0) Model Predictions													
Input File	Drilling Intervals	Durations of Discharge	Model Time Step	Depth of Water	Depth of Discharge	Pre-diluted Effluent Discharge Rate	Solids Deposition on the Seabed				Total Suspended Solids (TSS) Concentration in Water Column - (distances from the source)		
							Maximum Loading	Area Covered by Solids Thickness (ha)		Maximum Deposit Thickness	100 m	300 m	1 km
		sec	sec	m	m	bbls/hour	kg/m^2	> 10 cm	> 1 cm	cm	mg/l	mg/l	mg/l
CASE-2.inp	MLC ROV	604,800	14,400	44.0	41.56	13,529	3,198	0.673	4.590	120.7	530.9	109.3	12.6
CASE-1.inp	MLC ROV	604,800	7,200	44.0	41.56	13,529	1,490	0.826	3.437	56.2	200.00	65.00	12.50

Table 7-2: Model Results – The OOC model version 2.5 (1999) and version 3.0 (2013)

The OOC Model Predictions									
Input File	Drilling Intervals	Durations of Discharge	Model Time Step	Depth of Water	Depth of Discharge	Pre-diluted Effluent Discharge Rate	The OOC Model Version (Release Date)	Solids Deposition on the Seabed	
								Maximum Loading	Maximum Deposit Thickness (porosity = 0.0)
		sec	sec	m	m	bbls/hour		kg/m^2	cm
CASE-2.inp	MLC ROV	604,800	14,400	44.0	41.56	13,529	2.5 (12/2/1999)	2,362	89.1
							3.0 (12/16/2013)	3,198	120.7
CASE-1.inp	MLC ROV	604,800	7,200	44.0	41.56	13,529	2.5 (12/2/1999)	298	11.2
							3.0 (12/16/2013)	1,490	56.2

SECTION 8.0 REFERENCES

Alam, M. and Brandsma, M.G. “GUIDO – Graphical User Interface for the OOC Model for Offshore Discharges, User Guide, Version 7.0”, April 2013.

Brandsma, M.G. and Smith J.P. “Offshore Operators Committee Mud and Produced Water Discharge Model – Report and Users Guide”, December 1999.

APPENDIX A: INPUT FILES CASE-2.INP AND CASE-1.INP

A.1 CASE-2.INP FILE

```
MUD

exmud001_msf.in -CASE-1

FULL

NOSQUEEZE

SAVEDYN

PVALL

DISCHARGE

13529,  0.67, 136.35,  0., 90. !

1640.  328.                !XRIG[dueS](ft) ZRIG[dueE](ft)

604800                             ! DISCHARGE LASTS HOUR

8.72  ! lb/gal

'Sol1'    2.65    0.0009573   0.000003

'Sol2'    2.65    0.0007180   0.000047

'Sol3'    2.65    0.0008376   0.000664

'Sol4'    2.65    0.0003590   0.007383

'Sol5'    2.65    0.0002393   0.038680

'Sol6'    2.65    0.0021539   0.115392

'Sol7'    2.65    0.0019146   0.236888

'Sol8'    2.65    0.0017949   0.459383

'Sol9'    2.65    0.0029916   0.871619

GRID

200   50 ! GRID IS 60 SQUARES EW BY 60 SQUARES NS

 65.62   ! GRID SQUARE SIZE IS 32.8 FT(20 M)

CONSTANT

144.35           !CONSTANT WATER DEPTH OF  FT

OUTPUT

0 0 1 1   10 ! PRINTED LISTING OF EVERY TENTH DYNPLUME STEP

44               ! SPOT PROFILES WITH 30 POINTS FROM SURFACE TO BOTTOM
```

```
 0                ! NO PLUME CURTAIN PROFILES
 0                ! NO SPOT PROFILES REQUESTED
 0 0 0          ! NO RADIUS PROFILES
 0                !NO SEDIMENT TRAPS
 0
ALLSOLIDS
BO           ! ask for bottom accumulation of solids at 72000 seconds
3 302400.    !604800.          144000   7200 works
-1
```

AMBIENT

```
      3       1 999999.0
     -2
    0.00    0.23   90.00          ! data set 1
  144.35    0.23   90.00           ! data set 1
      1       2 999999.0
     0.0    0.0    32.0
   144.35   0.0    32.0
     1 999999. ! ONE SET OF SEA STATE PARAMETERS
0.1        12.,,,
```

TIMESTEP

```
14400.
```

END

A.2 CASE- 1. INP FILE

```
MUD
exmud001_msf.in -CASE-1

FULL

NOSQUEEZE

SAVEDYN

PVALL


DISCHARGE
13529,  0.67, 136.35,  0., 90. !
1640.  328.              !XRIG[dueS](ft) ZRIG[dueE](ft)
604800                           ! DISCHARGE LASTS HOUR
8.72  ! lb/gal
'Sol1'    2.65    0.0009573   0.000003
'Sol2'    2.65    0.0007180   0.000047
'Sol3'    2.65    0.0008376   0.000664
'Sol4'    2.65    0.0003590   0.007383
'Sol5'    2.65    0.0002393   0.038680
'Sol6'    2.65    0.0021539   0.115392
'Sol7'    2.65    0.0019146   0.236888
'Sol8'    2.65    0.0017949   0.459383
'Sol9'    2.65    0.0029916   0.871619


GRID
200   50 ! GRID IS 60 SQUARES EW BY 60 SQUARES NS
 65.62   ! GRID SQUARE SIZE IS 32.8 FT(20 M)
CONSTANT
144.35           !CONSTANT WATER DEPTH OF  FT

OUTPUT
0 0 1 1   10 ! PRINTED LISTING OF EVERY TENTH DYNPLUME STEP
44              ! SPOT PROFILES WITH 30 POINTS FROM SURFACE TO BOTTOM
 0                ! NO PLUME CURTAIN PROFILES
 0                ! NO SPOT PROFILES REQUESTED
 0 0 0          ! NO RADIUS PROFILES
 0                !NO SEDIMENT TRAPS
 0
ALLSOLIDS
BO           ! ask for bottom accumulation of solids at 72000 seconds
3 302400.    !604800.          144000   7200 works
-1

AMBIENT
       3       1 999999.0
      -2
    0.00    0.82   90.00          ! data set 1
  144.35    0.82   90.00           ! data set 1
       1       2 999999.0
     0.0    0.0    32.0
   144.35   0.0    32.0
     1 999999. ! ONE SET OF SEA STATE PARAMETERS
0.1        12.,,,

TIMESTEP
7200.


END
```

This is the last page of this document.